

# Grain-Stream Velocity Measurements

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**P**HYSICAL grain damage is a common problem in the grain industry. The technological changes in grain production and harvesting, especially the recent shift to field shelling of corn, have added to this problem. Either field-shelled or artificially dried corn is often brittle and easily broken. With the repeated handling common in commercial marketing channels, breakage of the brittle grain frequently is extensive enough to lower its value.

A study was conducted† to determine the cause and extent of grain damage by various commercial handling techniques (4)\*. In the course of this study, it appeared that velocity was a common denominator of grain breakage. The project was extended to include the measurement of grain velocities produced by the handling methods tested, and to correlate these with grain breakage. High-speed photography was used to measure grain velocity. Reported in this paper are the stream velocities measured for yellow corn, yellow soybeans, and hard, red winter wheat in freefall drop and when handled by a grain thrower and a bucket elevator.

## Previous Work

Several authors have contributed data on terminal velocity as well as on other aerodynamic characteristics of grains. Such data are used in the study of pneumatic conveying, threshing and cleaning operations and other related areas. Hawk, Brooker and Cassidy (7) reported terminal velocities as well as other characteristics for various grains. Kiker and Ross (10) measured the velocity of lupine seeds in free fall. There was no work reported that measured velocities of grain in streams of sizes used in commercial handling practice.

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\* Numbers in parentheses refer to the appended references.

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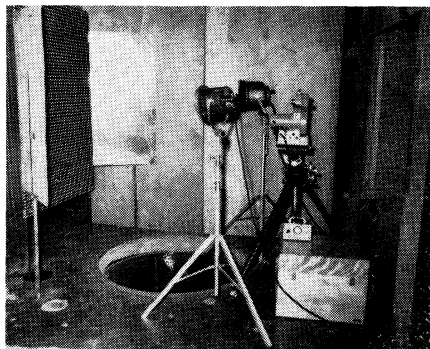


Fig. 1 High-speed photography setup for the drop tests

High-speed photography has been used previously to measure particle velocities. Brusewitz and Wolfe (1) and Collins, Harris, and Burkhardt (3) used high-speed photography to measure the velocity of forage in a pneumatic conveying system. Kiker and Ross (10) measured lupine seed velocity by high-speed photography. Hyzer (9) illustrates a wide range of engineering studies in various industries using high-speed photography.

## Test Procedure

A Red Lakes Laboratory Hycam model K20S4E† 16 mm motion picture camera (Fig. 1) was used to photograph various grain streams. This camera was equipped with a timing light generator which placed light marks on the film edge at intervals of one millisecond. A background of either a 3-in. or a ½-in. square grid was placed behind the grain stream. Film speeds of 2,000 to 7,000 pictures per sec were used.

When the developed film was viewed, the distance a particular kernel traveled was measured against the grid background. The apparent velocity was corrected for the difference in the distance from the camera to the grain stream and from the camera to the grid background.

The camera could not "see" into the center of the grain stream and the velocity measurements were made on kernels in the outer layers. Measurements were made only on those kernels that appeared to be an indigenous part of the stream, and it was assumed that they were moving at the same velocity as the stream.

Kernel velocities reported are aver-

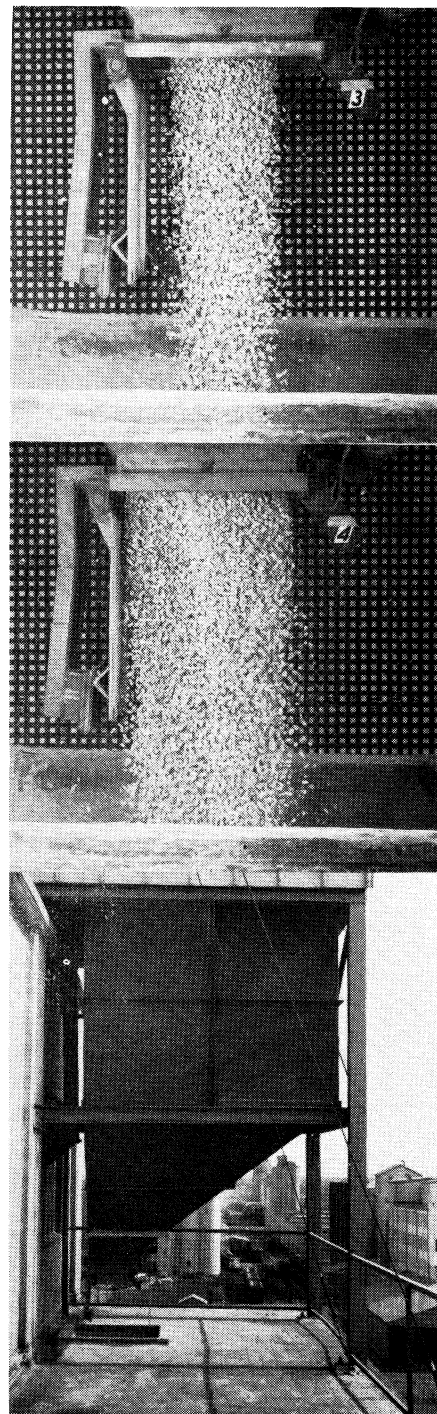


Fig. 2 The drop tests: corn streams from 8-in.-diameter orifice (top) and 12-in. orifice (center). At bottom is 350-bu holding bin

ages for a travel distance of six inches and are not instantaneous velocities.

The grain for the free-fall drop tests was first placed in a 350-bu holding bin (Fig. 2). The bin bottom was

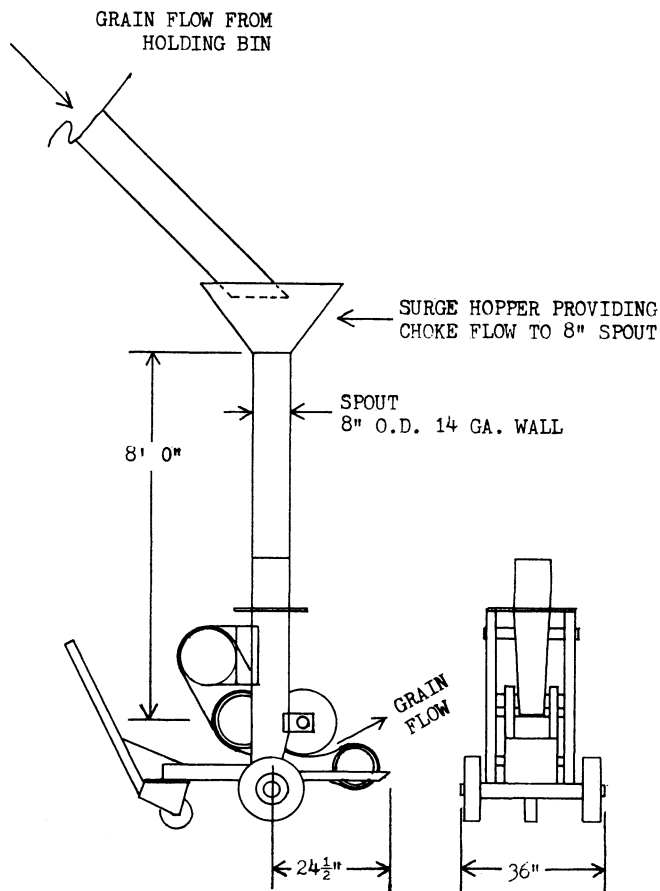


Fig. 3 Grain thrower used for breakage tests (Stephan-Adamson 16-in. swivel piler)

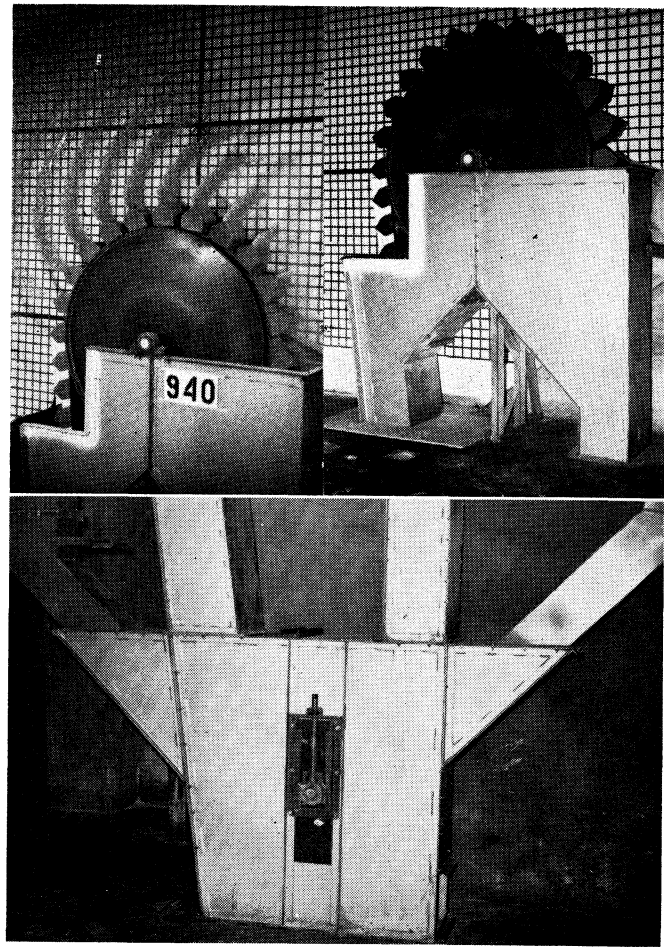


Fig. 4 Bucket elevator used in the tests

fitted with a trap-door type of discharge that was either fully open or fully closed. Streams from interchangeable 12 and 8-inch-diameter round orifices were measured at distances of 0, 10, 41, 69, and 85 ft below the edge of the orifice.

A grain thrower of the type used in these tests (Fig. 3) is often installed at the discharge of a ship-loading spout to throw grain to the far corners of the cargo hold. Velocity measurements were taken at distances of 0, 10, 20, and 25 ft from the thrower-tail pulley center line. Thrower belt speeds of 762, 576, and 360 in. per sec (ips) were used.

A conventional bucket elevator (leg) was used, except the discharge head was not enclosed as shown in Fig. 4. Discharge was free and unrestricted. Screw Conveyor Corp. Nu-Hy 9 x 6-in. buckets and Link-Belt Co. high-speed 9 x 6-in. buckets were tested at belt speeds of 130 and 188 ips. Both types of buckets were spaced 8 in. apart on the belt. Head pulley diameter was 60 in. and tail pulley diameter was 30 in.

#### Analysis Procedure

Because there was considerable variation in the velocities observed, measurements were repeated either nine or

ten times, and the results analyzed statistically for significant differences between mean velocities. Two statistical treatments were used, analysis of variance and the Q test. A library computer program (5) was used for the analysis of variance. The Q test was used as described by Snedecor (15). Significance or no significance was declared at the 95 percent confidence level.

#### Velocity Results

The grain-stream velocities measured are summarized in Tables 1, 2 and 3 for the three principal handling methods studied.

#### Free-Fall Drop Tests

Free-fall velocities up to 828 ips (4140 ft per min) were observed at a drop distance of 85 ft (Table 1). There was no significant difference between corn and wheat velocities. The free-fall velocities of soybeans averaged 6 percent greater than for corn or wheat. Hawk, Brooker and Cassidy (7) found that soybeans had lower aerodynamic drag coefficients than either wheat or corn. Assuming that air resistance is a significant factor, less aerodynamic drag could account for the greater soybean velocity. Fig. 5 shows the relationship between free-fall velocity and drop

TABLE 1. FREE FALL VELOCITIES OF GRAIN STREAMS

Grain	Orifice diameter, in.	Mean grain-stream velocity for drop distances (in feet) of:				
		0	10	41	69	85
	inches	ips	ips	ips	ips	ips
Corn	8	72	256	470	567	682
Corn	12	80	271	446	606	800
Soybeans	8	71	264	482	652	726
Soybeans	12	79	264	501	652	828
Wheat	8	68	264	478	642	652
Wheat	12	74	277	488	558	800

TABLE 2. THROWER GRAIN STREAM VELOCITY

Grain	Thrower belt speed	Mean grain stream velocity at distance from thrower (in feet) of:			
		0	10	20	25
	ips	ips	ips	ips	ips
Corn	762	442	427	—	500
Corn	576	428	387	—	426
Corn	360*	316	265	297	—
Soybeans	762	483	411	—	466
Soybeans	576	437	397	—	418
Soybeans	360*	319	267	305	—
Wheat	762	551	393	—	497
Wheat	576	472	342	—	456
Wheat	360*	330	253	302	—

\* Measurements at 20 ft were made because the belt speed was not sufficient to throw the grain 25 ft.

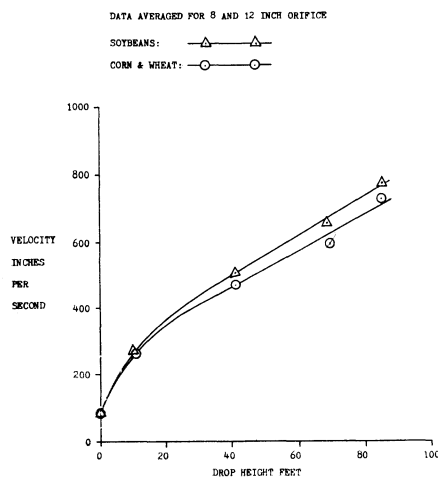


Fig. 5 Grain velocity versus drop height

height. The corn and wheat data were averaged together since there was no significant difference in free-fall velocities between these two grains.

The velocity of a grain stream from a 12-in. orifice averaged 6 percent above that from an 8-in. orifice. The orifice size had little effect on velocities at drop heights less than 41 ft. It was observed that between 41 and 85 ft, the 8-in. orifice stream dispersed more and became less dense than the 12-in. orifice stream. Therefore, more kernels in the 8-in. stream were subjected to air resistance, resulting in slower velocities. The report on the quantitative breakage results from these tests (4) shows more breakage in an 8-in. stream than in a 12-in. stream, even though these results show the velocity to be lower. Perhaps the amount of scatter in the stream also affects the breakage.

#### Thrower Tests

The maximum grain velocities in the grain-thrower tests were about one-third less than in the grain-drop tests.

TABLE 3. VELOCITY OF GRAIN DISCHARGING FROM A BUCKET ELEVATOR

Grain	Bucket style	Mean grain stream velocities at belt speed (fpm) of:	
		130	188
		ips	ips
Corn	Nu-Hy	186	256
Corn	Link-Belt	193	261
Soybeans	Nu-Hy	188	264
Soybeans	Link-Belt	186	259
Wheat	Nu-Hy	191	253
Wheat	Link-Belt	194	267

less than one-third these in the drop tests.

Elevator belt speed was the largest factor affecting the velocity of grain discharging from a bucket elevator. Grain velocity increased with increased belt speed (Table 3). Bucket style was not a significant variable. There was no significant difference between the velocities of corn and soybeans and between soybeans and wheat. The velocities of the corn were slightly lower than for wheat.

The data variability is shown in Table 4. Means and variances were averaged for each handling method to arrive at the pooled values shown in the table. Pooled standard deviation is the square root of the pooled variance. The coefficient of variation normalizes the data for differences in the absolute values of velocity. The trend is to increase variability with increasing velocity.

The test variables that significantly affected grain-stream velocity are shown in Table 5.

#### Predicting Free-Fall Grain Velocity

The free-fall grain velocities observed were compared with the theoretical velocities attainable. Neglecting air resistance, all bodies fall with the same acceleration due to gravity. The theoretical free-fall velocity equation can be written as follows:

$$V = 96.24 D^{0.5} \quad [1]$$

where  $V$  = velocity, in. per sec

TABLE 4. VELOCITY VARIABILITY

Test	Stream velocity			
	Pooled mean	Pooled standard deviation	Confidence interval*	Coefficient of variation†
	ips	ips	± ips	Percent
Free fall drop	436	13.09	30	3.0
Thrower	392	11.53	27	2.9
Bucket elevator	224	2.14	5	1.0

\* At 95 percent confidence level.

† Coefficient of variation is the standard deviation as a percent of the mean.

TABLE 5. VARIABLES SIGNIFICANTLY AFFECTING GRAIN-STREAM VELOCITY

Handling method	Variable	Significant
Drop	Grain	Yes
	Orifice size	Yes
	Drop height	Yes
Thrower	Grain	No
	Distance	Yes
	Belt speed	Yes
Bucket elevator	Grain	Yes
	Bucket style	No
	Belt speed	Yes

$D$  = vertical distance, ft

The theoretical free-fall velocity is linear with respect to the square root of the drop height. A linear regression analysis of the experimental data produced the following two equations relating grain velocity to the square root of the drop height:

12-in. orifice:

$$V = 51.3 + 73.3 D^{0.5} \quad [2]$$

8-in. orifice:

$$V = 59.9 + 67.0 D^{0.5} \quad [3]$$

These equations are based on the velocities of the three grains averaged together.

The grain started moving inside the bin and thus had a velocity upon reaching the discharge orifice. This phenomenon of "coring" produced velocities of 68 to 80 ips at the orifice and accounts for the intercept constant in the grain-velocity equations.

### Terminal Velocity

Hawk, Brooker and Cassidy (7) defined terminal velocity as the maximum velocity a single particle will achieve when falling freely in a still viscous fluid. They reported the following single-kernel terminal velocities for grain in air:

Grain	Single-kernel terminal velocity, ips
Soybeans	475 to 530
Corn	322 to 390
Wheat	256 to 313

As shown in Fig. 6, the velocity of the grain falling in a stream exceeded the single-kernel terminal velocity, but was less than the theoretical free-fall velocity. A single kernel is limited in velocity because of air resistance. However, a stream of grain acts as a mass and not all of the individual kernels are equally affected by aerodynamic drag. The maximum values of the single-kernel terminal velocity reported above were reached by the falling-grain stream at the following drop heights:

Grain	Drop Height at Which Stream Velocity* Equalled Kernel Terminal Velocity For:	
	8-in. orifice	12-in. orifice
Soybeans	49 ft	43 ft
Corn	24 "	21 "
Wheat	14 "	13 "

\* Stream velocities as predicted by equations —(2)— and —(3)—.

### Effect of Stream Velocity on Grain Breakage

The amount of grain breakage caused by the handling practices used were reported by Fiscus (4). The breakage in corn and soybeans is related to stream velocity as shown in Tables 6 and 7. Breakage was defined as kernel particles passing through wire-mesh screens with  $0.159 \times 0.159$ -in. square openings for corn and 0.158 by 0.5-in. rectangular openings for soybeans.

Wheat breakage was not compared to velocity because the magnitude of wheat breakage was small and showed no change with the variables that affected velocity. Also, the breakage data from the bucket-elevator tests were not used. The velocity measurements were made at the discharge head, while the breakage reported (4) occurred in the elevator boot.

Because of physical limitations in the drop tests, it was impossible to make velocity measurements at the same height that the breakage measurements were made. Therefore, equation [3] was used to predict grain velocity at the desired drop heights.

Fiscus (4) found that grain temperature and moisture significantly affected

TABLE 6. EFFECT OF GRAIN STREAM VELOCITY ON BREAKAGE IN FREE-FALL TESTS\*

Grain	Corn		Soybeans	
	Moisture, percent	Temperature, deg F	Moisture, percent	Temperature, deg F
	12.6	15.2	11.0	12.6
	25	31	32	50
Drop height, ft	Grain velocity†, ips		Mean breakage, percent	
100	730		13.82	9.55
71	625		10.83	5.03
40	484		5.86	0.86

\* Based on stream from 8-in. orifice falling on concrete at 45 deg angle.

† Velocity predicted by equation [3].

TABLE 7. EFFECT OF GRAIN STREAM VELOCITY ON BREAKAGE IN THROWER TESTS

Grain	Corn		Soybeans	
	Moisture, percent	Temperature, degrees F	Moisture, percent	Temperature, degrees F
	13.2	15.4	11.1	12.5
	49	34	39	41
Belt speed, ips	Mean grain velocity, ips*		Mean breakage, percent	
762	427		513	1.42
576	387		2.75	1.15
360	265		1.57	0.52
762	411			1.46
576	397			1.01
360	267			0.59

\* At 10 ft from thrower discharge.

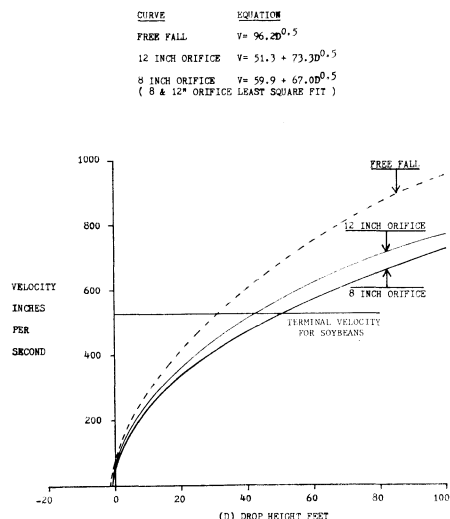


Fig. 6 Velocity versus drop height

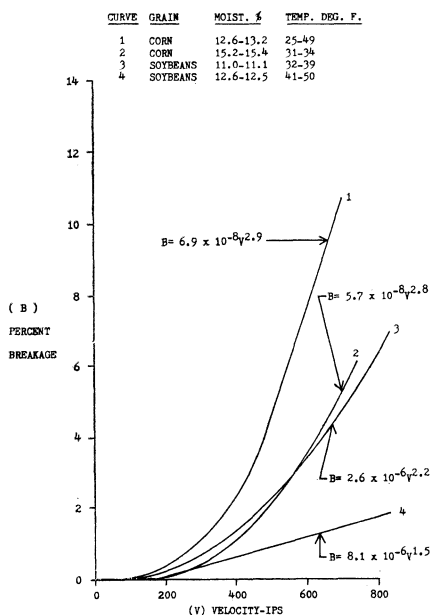


Fig. 7 Breakage versus velocity

breakage. Therefore, separate comparisons were made for the two moisture levels tested. Unfortunately grain temperatures and moistures were not identical in the drop and in the thrower tests.

Finally, breakage was found to be an exponential function of velocity in the form:

$$B = cV^n \quad [4]$$

where  $B$  = percent breakage

$V$  = velocity, ips

$c, n$  = constants varying with grain type, moisture and temperature

The experimental data were fitted to equation [4] by the method of least squares. Separate constants were determined for corn and soybeans at the two levels of temperature and moisture tested. The resulting curves with the equation for each curve are shown in Fig. 7.

Velocity accounted for from 79 to 99 percent of the variation in breakage in the four relationships shown. The effect of velocity on breakage was the greatest in those lots of grain that were at low moistures and temperatures and had the highest average breakage.

### Conclusions

1 The velocity attained by a falling stream of grain exceeded the terminal velocity of single kernels at drop distances of about 50 ft.

2 Grain velocities from the grain thrower used in this test were about equal to those of a stream of grain after 40 ft of free fall.

3 The velocity of grain discharging from the bucket elevator used in these

tests was about equal to that of a grain stream after a drop of 10 ft.

4 Breakage in grain was shown to be an exponential function of velocity.

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